VALUE-CHAIN OF BIOFUELS

Fundamentals, Technology, and Standardization

Edited by

Suzana Yusup

Nor Adilla Rashidi

ELSEVIER

Value-Chain of Biofuels

This page intentionally left blank

Value-Chain of Biofuels

Fundamentals, Technology, and Standardization

Edited by

SUZANA YUSUP

Higher Institution of Centre of Excellence (HICoE) Centre for Biofuel and Biochemical Research, Institute of Self-Sustainable Building, Department of Chemical Engineering, Universiti Teknologi PETRONAS, Seri Iskandar, Malaysia

NOR ADILLA RASHIDI

Higher Institution of Centre of Excellence (HICoE) Centre for Biofuel and Biochemical Research, Institute of Self-Sustainable Building, Department of Chemical Engineering, Universiti Teknologi PETRONAS, Seri Iskandar, Malaysia

ELSEVIER

Elsevier
Radarweg 29, PO Box 211, 1000 AE Amsterdam, Netherlands
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, United Kingdom
50 Hampshire Street, 5th Floor, Cambridge, MA 02139, United States

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

ISBN: 978-0-12-824388-6

For Information on all Elsevier publications
visit our website at https://www.elsevier.com/books-and-journals

Publisher: Candice Janco
Acquisitions Editor: Peter Adamson
Editorial Project Manager: Leticia M. Lima
Production Project Manager: Kamesh Ramajogi
Cover Designer: Miles Hitchen

Typeset by MPS Limited, Chennai, India

Contents

List of contributors *xiii*
Preface *xxi*

1. Overview of biomass conversion to biofuels **1**

Kin Wai Cheah, Martin J. Taylor, Geraint Evans, Abby Samson and Vasiliki Skoulou

Abbreviations 1
1.1 Introduction 1
1.2 Lignocellulosic biomass feedstock for biofuels production 5
1.3 Pretreatments of lignocellulosic biomass waste 12
1.4 Conversion methods of biomass waste to biofuels 17
1.5 Challenges, opportunities, and future perspectives 33
1.6 Conclusion 35
Acknowledgments 36
References 36

2. Conversion of biomass to biofuels **49**

Mohd Azlan Mohd Ishak, Asnida Yanti Ani, Syarifah Nursyimi Azlina Syed Ismail, Muhammad Luqman Md Ali and Razi Ahmad

Abbreviations 49
2.1 Conversion of biomass to biofuels 49
2.2 Thermochemical conversion technology of biomass to biofuels 51
2.3 Biochemical conversion 54
2.4 Transesterification 59
2.5 Conclusion 62
Acknowledgments 63
References 63

3. Biomass classification and characterization for conversion to biofuels **69**

Zul Ilham

Abbreviations 69
3.1 Introduction 69
3.2 Biomass composition analysis 70
3.3 Biomass-derived lipid for biodiesel 73

3.4 Catalysts for biodiesel production 78
3.5 Conclusion 83
References 83

4. Thermal degradation behavior and kinetic modeling of green solvents-delignified biomass: a sustainable biomass-to-energy approach 89

Andy Law Kai Wen, Jiuan Jing Chew, Chung Loong Yiin and Serene Sow Mun Lock

Abbreviations 89
4.1 Introduction 89
4.2 Methodology 93
4.3 Results and discussion 95
4.4 Conclusions 100
Acknowledgments 101
References 101

5. Pretreatment of fiber-based biomass material for lignin extraction 105

Syazmi Zul Arif Hakimi Saadon, Noridah Binti Osman and Suzana Yusup

Abbreviations 105
5.1 Introduction 105
5.2 Pretreatment 106
5.3 Background of lignin 114
5.4 Lignin extraction 118
5.5 Biomass applications in Malaysia 121
5.6 Conclusions 124
Acknowledgments 126
References 126

6. Microalgae cultivation for sustainable biofuel production 137

Sze Yu Chua, Yoke Wang Cheng, Man Kee Lam, Yaleeni Kanna Dasan, Wan Nadiah Amalina Kadir, Siti-Suhailah Rosli, Jun Wei Lim, Inn Shi Tan and Steven Lim

Abbreviations 137
6.1 Introduction 137
6.2 Suspended cultivation 139
6.3 Attached cultivation 142
6.4 Life cycle assessment of microalgae conversion to biofuels 148
6.5 Other microalgae applications 152
6.6 Conclusions 155
Acknowledgments 155
References 155

7. Hydrothermal liquefaction of algal biomass to bio-oil **159**

Jonas Karl Christopher N. Agutaya, Armando T. Quitain, Yik Lam Kam, Siti Zullaikah, Joseph Auresenia, Raymond R. Tan, Suttichai Assabumrungrat and Tetsuya Kida

Abbreviations 159
7.1 Introduction 159
7.2 Algae as a feedstock 160
7.3 Harvesting of algae 164
7.4 Hydrothermal liquefaction 167
7.5 Conclusions 174
References 175

8. Alternative jet fuels: biojet fuels' challenges and opportunities **181**

Rozzeta Dolah, Salman Zafar and Mohamad Zaki Hassan

Abbreviations 181
8.1 Introduction 181
8.2 Biooil refinement 186
8.3 Feedstock sustainability/potential biomass feedstock 189
8.4 Conclusions 192
Acknowledgements 193
References 193

9. Bioprocessing of sustainable renewable biomass for bioethanol production **195**

Mohd Asyraf Kassim, Tan Kean Meng, Ramizah Kamaludin, Azieyati Hani Hussain and Nurul Adela Bukhari

Abbreviation 195
9.1 Introduction 195
9.2 Bioethanol from renewable biomass 196
9.3 Pretreatment of the renewable biomass 203
9.4 Hydrolysis of the renewable biomass 212
9.5 Bioethanol formation 216
9.6 Strain improvement 221
9.7 Conclusions 224
Acknowledgment 225
References 225

10. Utilization of agricultural biomass for bio-butanol production 235

Mohamad Faizal Ibrahim, Nur Nabila Talib, Nur Haziqah Alias, Izza Nadira Abu Bakar, Suraini Abd Aziz and Phang Lai Yee

Abbreviations 235
10.1 Introduction 235
10.2 Agricultural biomass 236
10.3 Agricultural biomass for bioenergy 237
10.4 Bio-butanol from agricultural biomass 238
10.5 Bio-butanol 239
10.6 Conclusions 244
Acknowledgements 244
References 245

11. Oil palm biomass zero-waste conversion to bio-succinic acid 249

Shuhaida Harun, Abdullah Amru Indera Luthfi, Peer Mohamed Abdul, Nurul Adela Bukhari and Jamaliah Md Jahim

Abbreviations 249
11.1 Introduction 250
11.2 Oil palm biomass chemical potential 251
11.3 Reaping the benefits from biomass conversion 256
11.4 Historical perspective and importance of succinic acid 264
11.5 Bioconversion of carbon intermediates to bio-succinic acid 266
11.6 Issues/challenges and way forward 272
References 273

12. Iso-conversional kinetic and thermodynamic analysis of catalytic pyrolysis for palm oil wastes 277

Siaw Weii Hii, Bridgid Lai Fui Chin, Fanthagiro Rossi Stuard Anak Majing, Huei Yeong Lim, Adrian Chun Minh Loy, Chung Loong Yiin, Suzana Yusup, Armando T. Quitain, Menandro N. Acda, Pornkamol Unrean and Elisabeth Rianawati

Abbreviations 277
12.1 Introduction 277
12.2 Experiment materials and methods 279
12.3 Results and discussions 284
12.4 Conclusions 298
Acknowledgments 298
References 298

13. Recent progress in modeling and simulation of biomass conversion to biohydrogen **301**

Abrar Inayat, Rumaisa Tariq, Ola Alsaidi, Muhammad Shahbaz, Zakir Khan, Chaouki Ghenai and Tareq Al-Ansari

Abbreviations 301
13.1 Introduction 301
13.2 Kinetic modeling for biohydrogen production 303
13.3 Equilibrium modeling and simulation for biohydrogen production 307
13.4 Computational fluid dynamics modeling for biohydrogen production 309
13.5 Future prospective 311
13.6 Conclusions 311
References 311

14. Realizing higher value output from biomass conversion to biogas through the production of biohydrogen, biomethane, and biohythane **317**

Shaliza Ibrahim and Azam Akhbari

Abbreviations 317
14.1 Introduction to biogas production 317
14.2 Oil palm by-products as largely untapped biomass resources 318
14.3 Anaerobic digestion 320
14.4 Operational parameters for anaerobic treatment systems 321
14.5 Anaerobic bioreactor configurations 322
14.6 Revisiting biohydrogen 323
14.7 Biohythane 327
14.8 Bridging the gaps 327
Acknowledgments 331
References 331

15. Technical readiness level of biohydrogen production process and its value chain **335**

Muhammad Shahbaz, Tareq Al-Ansari, Abrar Inayat and Muddasser Inayat

Abbreviations 335
15.1 Introduction 335
15.2 Combustion 338
15.3 Gasification 339
15.4 Pyrolysis 341
15.5 Liquefaction 343
15.6 Challenges and barrier for commercialization 344
15.7 Way forward 346

15.8 Conclusion 347
Acknowledgments 347
References 348

16. Experimental investigation of the characterization of emissions from waste cooking oil biodiesel 357

Sajjad Porgar, Nejat Rahmanian, Asad Ibrar, Jian-Ping Li, Raj Patel and Xiuquan Sun

Abbreviations 357
16.1 Introduction 357
16.2 Procedure 359
16.3 Materials and equipment 359
16.4 Results and discussion 362
16.5 Conclusion 375
Acknowledgments 376
References 376

17. Techno-economic analysis of biomass thermochemical conversion to biofuels 379

Yi Fang, Wangliang Li and Siming You

Abbreviations 379
17.1 Introduction 379
17.2 Thermochemical conversion pathways 380
17.3 Techno-economic analysis 383
17.4 Challenges for tea of the thermochemical pathway 389
17.5 Conclusions 389
References 389

18. Economical aspect in biomass to biofuel production 395

Pritam Bardhan, Anuron Deka, Satya S. Bhattacharya, Manabendra Mandal and Rupam Kataki

Abbreviations 395
18.1 Introduction 395
18.2 Biomass selection 396
18.3 Biofuel production technologies: pros and cons 399
18.4 Scalability and economics of available techniques: an insight 412
18.5 Role of country's economy-policy formulation and execution 416
18.6 Conclusions and perspective 417
References 418

19. Biomass supply chain management and challenges **429**

Chun Hsion Lim, Sue Lin Ngan, Wendy Pei Qin Ng, Bing Shen How and Hon Loong Lam

Abbreviation 429

19.1 Introduction 429

19.2 Challenges associated with the biomass supply chain for biofuel production 431

19.3 Hazard and operability analysis approach 432

19.4 Critical review of biomass supply chain system challenges: hazard and operability analysis review approach 433

19.5 Conclusion 441

Acknowledgments 442

References 442

20. Biomass supply chain synthesis and optimization **445**

Wendy Pei Qin Ng, Bing Shen How, Chun Hsion Lim, Sue Lin Ngan and Hon Loong Lam

Abbreviations 445

20.1 Introduction 446

20.2 Mathematical formulation of biomass supply chain 447

20.3 Multicriteria optimization of biomass supply chain 450

20.4 Further reading 475

20.5 Conclusion 477

Acknowledgment 477

References 477

21. Oil palm biomass value chain for biofuel development in Malaysia: part I **481**

Soh Kheang Loh, Harrison Lik Nang Lau, Jalil Nursyairah, Daryl Jay Thaddeus and Vijaya Subramaniam

Abbreviations 481

21.1 Introduction 481

21.2 First-generation biofuels (palm biodiesel) 483

21.3 Advanced biofuels 494

21.4 Supply chain optimization (palm oil and oil palm biomass) 498

21.5 Conclusion 500

Acknowledgments 501

References 501

22. Oil palm biomass value chain for biofuel development in Malaysia: part II 505

Soh Kheang Loh, Abu Bakar Nasrin, Mohamad Azri Sukiran, Nurul Adela Bukhari and Vijaya Subramaniam

Abbreviations 505
22.1 Introduction 505
22.2 Second-generation biofuels 507
22.3 Policies related to biogas deployment 525
22.4 Issues and challenges 526
22.5 Conclusion 528
Acknowledgments 529
References 530

23. Renewable energy transformation in Malaysia through bioenergy production: Policy insights from spatially-explicit modeling 535

Muhammad Nurariffudin Mohd Idris and Haslenda Hashim

Abbreviations 535
23.1 Introduction 535
23.2 Policies insights from spatially-explicit modeling 540
23.3 Conclusions 549
Acknowledgments 551
References 551

24. Production, regulation, and standardization of biofuels: a Philippine perspective 553

Menandro N. Acda

Abbreviations 553
24.1 Introduction 553
24.2 Biofuels standard and regulations 560
24.3 Biofuel incentives 564
24.4 Biofuel research and development 565
24.5 Phillippines biofuel roadmap 566
24.6 Conclusions 566
References 567

Index 571

CHAPTER 4

Thermal degradation behavior and kinetic modeling of green solvents-delignified biomass: a sustainable biomass-to-energy approach

Andy Law Kai Wen[1], Jiuan Jing Chew[1], Chung Loong Yiin[2] and Serene Sow Mun Lock[3]
[1]Faculty of Engineering, Computing and Science, Swinburne University of Technology, Sarawak, Malaysia
[2]Department of Chemical Engineering and Energy Sustainability, Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS), Sarawak, Malaysia
[3]CO_2 Research Center (CO2RES), Department of Chemical Engineering, Universiti Teknologi PETRONAS, Seri Iskandar, Malaysia

Abbreviations

AIL	Acid insoluble lignin
ASL	Acid soluble lignin
DTG	Differential thermogravimetric
EFB	Empty fruit bunch
KAS	Kissinger-Akahira-Sunose
LTTMs	Low-transition-temperature mixtures
MSW	Malic acid-sucrose-water
TG	Thermogravimetric
TGA	Thermogravimetric analysis

4.1 Introduction

The depletion of fossil fuels has resulted in an inadequate amount of fossil fuels left to support the ever-growing demand for energy and further leads to the surge in global dependency on the nonrenewable fossil fuels to sustain the current energy demand. Thus, it is necessary for mankind to have an alternative source of energy, which is renewable and sustainable [1]. In this sense, the conversion of lignocellulosic biomass to value-added products such as biofuels and biochemicals has gained its popularity as lignocellulosic biomass resources are readily available, cheap, and renewable [2]. Lignocellulosic biomass consists of three main components, namely cellulose, hemicellulose, and lignin. The content of these components varies according to the type of lignocellulosic biomass whereby oil palm biomass is one of the most abundant biomass.

Value-Chain of Biofuels
DOI: https://doi.org/10.1016/B978-0-12-824388-6.00012-9

Index

Note: Page numbers followed by "*f*" and "*t*" refer to figures and tables, respectively.

A

Acetogenesis, 19, 57
Acid hydrolysis, 119
Acid pretreatment method, 210–211
Acid-based hydrolysis, 58
Acid-catalyzed transesterification, 78–79
Acidogenesis, 19, 57
Acidolysis. *See* Acid hydrolysis
Actinobacillus succinogenes, 250, 519
Advanced biofuels, 494–497
Agricultural biomass, 235–236
  bio-butanol from, 238–239, 241*t*
  for bioenergy, 237–238
  categories, 236
  chemical composition of, 237*t*
Agricultural mills, 547–549, 548*f*
Agriculture, lignin application in, 123–124
Alcogas, 555
Alcohol dehydrogenase gene (ADH), 223
Algae
  as feedstock, 160–164, 161*f*
  harvesting of, 164–167
    advantages and disadvantages, of various technologies, 168*t*
    dewatering process, 167
    thickening, 165–167
  macroalgae, 162*t*
  microalgae, 162*f*, 162*t*
Algogenic organic materials (AOM), 165
Alkali and alkaline earth metals (AAEM), 31
Alkali hydrolysis, 119
Alkali index, 509*f*
Alkaline catalyzed transesterification, 78–79
Alkaline pretreatment method, 211
Alkalinity, 321
Aluminosilicates. *See* Zeolites
Ammonia based pretreated biomass, 263
Ammonia fiber expansion (AFEX), 259–260, 263
Ammonia-based pretreatment, 259–260
Amylopeptine, structure of, 197*f*
Amylose, stucture of, 197*f*
Anaerobic bioreactor configurations, 322–323
Anaerobic conversion, steps in, 324*f*
Anaerobic digestion (AD), 55–58, 317, 319–321, 327–329
  acetogenesis, 57
  acidogenesis, 57
  for biogas production, 18–20
  enzymatic hydrolysis, 55–57
  methanogenesis, 57–58
  process of, 19–20
  stages of, 19*f*
Anaerobic process, 21, 317–318, 320–321, 325
Anaerobic treatment systems, operational parameters for, 321–322
Analytical hierarchy process (AHP), 452, 466–468
Andrew models, 306–307
Arabinoxylan, primary structure of, 253*f*
Arrhenius model, 304
Artificial water systems, 140
Ash, 72–73
Attached cultivation method, 142–148, 142*f*
  biofilm development, 143–144, 143*f*
  challenges of, 147–148
  enclosure approach, 144–147, 144*f*
  nonenclosure approach, 144–147, 144*f*, 145*t*
Auto-flocculation, 165–166
Automatic Pricing Mechanism scheme, 535–536
Available techniques, scalability and economics of, 412–416

B

B5, B7
  and B10 program, implementation of, 486–489
B20 and B30 vehicle trials, 492*t*
B20/beyond, 489–490
B100 field test, DBKL UD truck used for, 493*f*
Bacillus firmus K-1, 402–403
Bacillus licheniformis, 325
Ball milling, 12–14, 13*f*
BeWhere Malaysia model, 540–541, 547–549
"BioActiv BD 100", 565

Bio-based succinic acid (BSA), 250−251, 264−266, 268−272
Bio-butanol, 239−244
from agricultural biomass, 238−239, 239*t*
characteristics, 239−240, 240*t*
fermentation process, 241−244, 242*f*
microorganisms producing, 240−241, 241*t*
Biocatalyst transesterification (BT), 82−83
Biochar experimental kit (BEK), 514−516
Biochemical conversion, of biomass, 54−59
anaerobic digestion, 55−58
fermentation, 58−59
transesterification, 59−62
Biochemical processes, 4
Bio-compressed natural gas (Bio-CNG), 524, 525*f*, 525*t*
Biodiesel, 483, 558−560
heat of combustion for, 363*t*
oxygen emission of, 371
Biodiesel production, catalysts for, 78−83
alkali and acid-catalyzed transesterification, 78−79
biocatalyst transesterification, 82−83
in situ transesterification, 81
microwave-assisted transesterification, 80
supercritical transesterification, 81−82
two-step acid base transesterification, 80
Biodiesel production rig, 360*f*
Bioenergy production, renewable energy transformation in Malaysia
spatially-explicit modeling, policies insights from, 540−549
achievement of decarbonization target, 549
agricultural mills, 547−549
BeWhere Malaysia model, 540−541
power and heat sectors, power tariff subsidy drives decarbonization in, 542−545
power, heat, and transport sectors, carbon price drives decarbonization in, 545−547
scenario description, 542
Bioethanol (C_2H_5OH), 20, 195−196, 557−558
and biochemicals, 516−519
formation, 216−221, 217*t*, 218*f*
advantages and disadvantages of, 222*t*
consolidate bioprocessing, 220−221
separate hydrolysis and fermentation process, 218−219
simultaneous saccharification and fermentation process, 219−220
from renewable biomass, 196−203
first-generation, 196−198
second-generation, 199−201
third-generation, 201−203
Bio-flocculation, 165−166
Biofuel feedstock quality, 508*f*
Biofuel incentives, 564−565
Biofuel Industry Bill 2006, 485
Biofuel production, economical aspect in biomass to
available techniques, scalability and economics of, 412−416
biofuel production technologies, 399−412
cleaning and pretreatment, 399−403
enzyme catalytic conversion, 408−409
hydrolysis, 403−404
pyrolysis, 409−412
saccharification and fermentation, 404−406
transesterification, 406−408
biomass selection, 396−399
cellulose, 397
composition, 396−399
energy conversion, 399
hemicellulose, 398
lignin, 398
starch, 398−399
country's economy-policy formulation and execution, role of, 416−417
Biofuel production technologies, 399−412, 414*t*
challenges associated with the biomass supply chain for, 431−432
techno-economic studies of, 384*t*
Biofuel research and development, 565
Biofuel, representation of transformation of biomass to, 401*f*
Biofuels Act of 2006, 556, 558−559, 564−566
Biofuels Law, 560−561
Biofuels standard and regulations, 560−563
Biofuels, 49
biochemical conversion route for, 34−35
biodiesel, 558−560
bioethanol, 557−558
biomass waste to, conversion methods, 17−33
biochemical routes, 17−22
thermochemical route, 22−31
challenges, opportunities, and future perspectives, 33−35

conversion of biomass to, 49–51
incentives, 564–565
lignocellulosic biomass feedstock for, 5–11
phillippines biofuel roadmap, 566
production pathways, 10*f*
research and development, 565
standard and regulations, 560–563
types of, 9–11
Biofuels, techno-economic analysis of biomass thermochemical conversion to
techno-economic analysis, 383–389
catalytic fast pyrolysis and hydro-processing, 385
fast pyrolysis, 383–385
gasification, 386–387
hydrothermal liquefaction, 387–389
methodology, 383
pyrolysis, 383–386
slow pyrolysis, 385–386
thermochemical conversion pathways, 380–383
gasification, 382
hydrothermal liquefaction, 382–383
pyrolysis, 380–382
thermochemical pathway, challenges for tea of, 389
Biogas, 330*t*, 525*t*, 526–528, 527*f*
production, 317–318
Biogas deployment, policies related to, 525–526
Biogas Environmental Engineering Sdn. Bhd. (BEE), 520
Biogas systems developed, performance of, 521*t*
Biogas utilization option, 524–525
Biohydrogen, 318, 324–325
revisiting, 323–327
Biohydrogen production
from biomass, thermochemical conversion routes of, 336*f*
computational fluid dynamics modeling for, 309–310
equilibrium modeling and simulation for, 307–309, 308*t*
kinetic modeling for, 303–307
Biohydrogen production process/value chain, technical readiness level of
combustion, 338–339
commercialization, challenges and barrier for, 344–346
biomass handling and storage, 346
supply chain, 346
technical challenges, 345
gasification, 339–341
liquefaction, 343–344
pyrolysis, 341–343
stakeholder relationship, 347
way forward, 346–347
policy and investment, 346–347
social awareness and marketing, 346
Biohythane, 327
Biological pretreatment method, 209
Biomass, 1–2, 49, 105, 302, 380, 528
to biofuels, conversion technology of, 51
biochemical, 54–59
thermochemical, 51–54
categories, 105
characteristics of, 50
composition analysis, 70–73
conversion to fuels, 3
-derived lipid for biodiesel, 73–78
different organic, inorganic, and fluid matter present in, 397*t*
different types of, 397*t*
feedstock compositions for, 71*t*
first-generation, 2
gasification of, 185
generations of, 49–50
lignocellulosic
availability of, 2
for biofuels production, 5–11
needs for, conversion into biofuels, 182
physiochemical properties of, 5–8
primary components of, 70
ash, 72–73
cellulose, 70–71
hemicellulose, 72
lignin, 72
volatile matter, 72
source of, 2
types of, for biofuel production, 50*f*
various conversion processes of, 401*f*
waste conversion pathways to biofuels, 7*f*
Biomass conversion pathway, 459*f*
Biomass conversion technology, 256–257, 302*f*
Biomass-derived lipid, for biodiesel, 73–78
lipid feedstocks, for food security, 75–76
dirty waste and used recycled oil, 76–78
microalgae, 76

Biomass-derived lipid, for biodiesel (*Continued*)
nonedible oil crops, 75–76, 75*t*
refined edible clean oil, 74–75
transesterification, 73–74, 73*f*
Biomass gasification (BG), 386–387
Biomass handling and storage, 346
Biomass integrated gasification and Fisch-Tropsch (BOIG-FT), 387
Biomass into energy, conversion of, 338
Biomass pellet (PLT), 449
Biomass preparation, 279
Biomass recycling practices, system boundary in evaluation of, 498*f*
Biomass reforming (BR), 386–387
Biomass selection, 396–399
Biomass supply chain management and challenges
biofuel production, challenges associated with the biomass supply chain for, 431–432
biomass supply chain system challenges, 433–441
hazard and operability analysis approach, 432–433
Biomass supply chain synthesis/optimization
mathematical formulation of, 447–450
illustrative case study, 449–450
typical mathematical constraints for, 448–449
multicriteria optimization of, 450–475
analytical hierarchy process, 466–467
approaches, comparison of, 475
economic data, 460
environmental data, 460–463
illustrative case study, 457–467
max–min aggregation approach, 453
multiobjective function formulation, 451–457
principal component analysis-aided optimization approach, 454–457
social data, 464–466
technology selection, 467–471
transportation design, 471–475
weighted-sum approach, 451–453
Biomass supply chain system, 436*f*
challenges, 433–441
Biomass supply chain, 447
biorefinery synthesis, 449*f*
mathematical formulation of, 447–450
illustrative case study, 449–450
typical mathematical constraints for, 448–449
multicriteria optimization of, 450–475
multiobjective function formulation, 451–457
sustainability measurement, key indicators for, 451*f*
optimized illustration model of, 450*f*
optimum supply chain synthesis, parameters used for, 450*t*
typical movement or flow of, 446*f*
Biomass-to-gaseous fuel, 519–525
Biomass-to-liquid (BTL), 528
Biomass-to-liquid fuel, 514–519
Biomass-to-solid (BTS), 510–511, 528
Biomass-to-solid fuel, 510–514
Biomethane (BioCNG), 537–540
Biooil
vs. petroleum fuel, 187*t*
refinement, 186–189
upgrading methods, 188–189
chemical, 189, 190*t*
mapping of, 191*t*
physical, 188, 188*t*
property analysis, 189
uses of, 186–187
Bio-oil production
challenges of, 33–34
pyrolysis and hydrothermal liquefaction for, 23–27
Bio-SNG project, 341
Bio-succinic acid, 264–270
advantages and disadvantages of, 268*t*
Bio-succinic acid, oil palm biomass zero-waste conversion to
biomass conversion, benefits from, 256–263
ammonia based pretreated biomass, 263
ammonia-based pretreatment, 259–260
biomass conversion technology, 256–257
deep eutectic solvent pretreatment, 260–261, 263
enzymatic and chemical hydrolysis, 261–263
sodium hydroxide (NaOH) pretreated biomass, 261–263
sodium hydroxide pretreatment, 257–258
bio-succinic acid, carbon intermediates to, 266–272
bio-succinic acid, fermentative production of, 266–270

oil palm-derived solid biomass, enhanced bio-succinic acid production from, 270–272
oil palm biomass chemical potential, 251–255
succinic acid, historical perspective and importance of, 264–266
bio-succinic acid, importance of, 264–266
historical perspective, 264
Briquettes, pellets/torrefied solid biofuel, 510–513
Bubble washing, 361–362
Bureau of Product Standards (BPS), 560–561

C

Calcium oxide, 78–79
Calophyllum inophyllum oil, 406–408
Cambridge Electric Design Power 1401 Analog to Digital Converter, 359–360
Capital expenditure (CAPEX), 460
Carbon capture and storage (CCS), 3
Carbon dioxide (CO_2), 271, 278, 286, 339, 341, 358–359, 369, 369*f*, 370*f*, 520–522, 535–536, 540–542, 545–547, 549, 550*f*
Carbon monoxide (CO), 358–359, 367–369, 367*f*, 368*f*
Catalyst preparation, 279
Catalysts, 52
homogeneous, 60
heterogeneous, 60
types of, 26
Catalytic fast pyrolysis (CFP), 385
Catalytic fast pyrolysis and hydro-processing, 385
Catalytic fast pyrolysis with hydrogen supply (CFPHS), 380–381
Catalytic pyrolysis, 26
Catalytic transesterification, 59–60
Cellulase, 408
Cellulignin, 58
Cellulose, 70–71, 251–252, 397, 398*f*
Cellulose hydrolysis, 215
Centrifugation, 167
Chemical compositions, 508*f*
Chemical flocculation, 165–166
Chemical pretreatment, 14–16, 110
Chemrez Technologies, Inc., 565
Chlorella, 494–495, 497*f*
Clean Air Act, 560–561
Cleaned syngas, 28
Cleaning and pretreatment, 399–403, 402*f*
Clostridium acetobutylicum, solventogenesis fermentation by, 243, 243*f*
Clostridium pasteurianum, 325
CO_2 reduction, microalgae in, 152–153
Coagulation, 165–166
Coats-Redfern model, 281–282, 289–298
Coconut methyl ester (CME), 556*f*, 559–561, 559*t*, 565
Coconut oil (CNO), 555, 555*f*, 558–560
Combined heat and power (CHP), 341, 513–514, 513*f*, 524, 537–540
Combustion and torque, heat of, 362–364
Combustion for diesel, heat of, 363*t*
Combustion, 3, 338–339, 365–367
Commercialization, challenges and barrier for, 344–346
Composition, 396–399
Computational fluid dynamics (CFD), 309–310, 310*t*
Consolidate bioprocessing (CBP), 220–221
Continuous stirred tank reactors (CSTR), 322, 325
Conventional process, bioethanol production, 197–198
Country's economy-policy formulation and execution, 416–417
Cradle to bioenergy (CTB), 148
Cradle to consumption (CTC), 148
Cradle to grave (CTG), 148
Crude palm oil (CPO), 483–484, 542, 545–547, 549

D

Dark fermentation, biohydrogen production by, 325–326
Dark fermentation process, different continuous reactors operated under, 326*t*
Decarbonization target, achievement of, 549
Decision making, 537
Deep eutectic solvent (DES), 120–121, 260–261, 263
Deep eutectic solvent pretreatment, 260–261
Densification, 22–23
Department of Energy (DOE), 556, 560–561, 566
Department of Environment and Natural Resources (DENR), 555–556, 558, 560–561
Derivative thermogravimetric (DTG), 284–286, 285*f*, 288

Devolatilization, 288
Dewatering process, 167
Differential thermogravimetric (DTG), 94, 96–99, 98*f*
Dilemma, 318
Dirty oil-based biodiesels, 77*t*
Disk milling, 12, 13*f*
Dispersed air flotation, 166
Dissolved air flotation, 166
Distillation, 188*t*
Dried long fiber (DLF), 446, 449
Drop-in biofuels, 181–182
  feedstock sustainability/potential biomass feedstock, 189–192
  lipid-based raw materials for, 192
  resource base, and sustainability, 189–192
  technology options in, 183–186
    biochemical conversion process, 185–186
    oleochemical conversion process, 183–184, 184*f*
    production pathways, 183
    thermochemical conversion process, 184–185, 184*f*
Dunaliella salina, 62

E

Economic data, 460
Edible feedstock, biofuel from, 483
Elaeis guineensis, 481–482
Electrolysis, 166
Electrolytic flotation, 166
Electrophoresis, 166
Empty fruit bunches (EFBs), 186, 499, 505–507, 510–518, 512*f*, 512*t*, 515*t*, 517*f*, 518*f*, 524
  kinetic modeling, 94–95
  lignin content, determination of, 93–94
  pretreatment of, 93
  thermogravimetric analysis, of untreated and delignified, 94
Emulsification, 188*t*
Energy conversion, 399
Energy Research and Testing Laboratory Services (ERTLS), 561
Energy Utilization Management Bureau (EUMB), 561
Engine Control Unit, 367–368
Engine, characteristics of, 360*t*
Enterobacter cloacae, 325
Environmental data, 460–463
Environmental Quality Regulations, 524–526
Enzymatic and chemical hydrolysis, 261–263, 262*t*
Enzymatic hydrolysis process, 55–58, 110, 120, 212–216
Enzyme catalytic conversion, 408–409, 410*t*
Equivalence ratio (ER), 339–340
EU's Renewable Energy Directive (EU RED), 498–499
Eucalyptus tail gas reactive fast pyrolysis (ETGRFPH), 383–385
Extracellular polymeric substance (EPS), 142, 143

F

Fast pyrolysis, 380–381, 383–385
Fast pyrolysis with hydro-processing (FPH) technology, 383
Fatty acids, 162–163
Feed-in tariff (FiT), 526–528, 535–536
Feedstock
  algae as, 160–164, 161*f*, 162*t*
  pretreatment of, 106
Fermentation process, 58–59, 302–303
  acid/base pretreatment, 58
  for bio-butanol, 241–244, 242*f*
  for bioethanol production, 20–22
  enzymatic hydrolysis, 58
  of LCFA, 19
  process, 59
  of xylose-rich/pentose sugar, 224
Fiber-based biomass, 105
Filtration, 167
First-generation bioethanol, 196–198
First-generation biofuels, 2, 483–494
First-generation biomass, 50
Fischer–Tropsch synthesis, 28
Five transportation modes, dimension and load limit of, 460*t*
Flash pyrolysis, 160
Flocculation, 165–166
  types of, 165–166
Flotation technique, 166
Fluidized bed (FB), 14
Food and Agriculture Organization (FAO), 482
Food supply, 416
Forest Land Grazing Management Program, 558
Free fatty acids (FFA), 484–485

Fresh fruit bunches (FFB), 250–251, 481–482, 483*f*, 484, 505–506, 506*t*, 513
F-T process, 185
Fuel consumption, 365–367, 366*f*
Fuel industries, lignin application in, 124
Full and partial load profiles, 362*t*
Full load
  CO emission, 367*f*
  CO_2 emission, 369*f*
  NO_x emission, 370*f*
  O_2, 372*f*
  power curve and fuel consumption at, 364*f*
  THC emission, 373*f*

G

Gaps, bridging, 327–331
Gases composition, 340
Gasification, 3, 53–54, 54*t*, 302–303, 339–341, 382, 386–387
  catalysis in, 30–31
  catalysts, 30–31
  vs. pyrolysis, 33
  for syngas production, 27–31, 27*f*, 29*t*
  technology, 413–415
Gauss-Newton algorithm, 307–309
GC-FID test, 362
Geometric mean, 466–467
Global Green Synergy Sdn. Bhd., 511–512
Glycerol-3-phosphate dehydrogenase (GDP), 223–224
Glycolysis, 185–186
Gompertz model, 304, 306–307
Granular starch hydrolysis (GSH) process, 197–198
Gravity sedimentation, 166
Green supply chain management (GSCM), 446
Greenhouse gas (GHG), 159, 182, 277–278, 379–380, 385, 489, 493–494, 498–499, 517*f*, 519–522, 525–526, 535–537, 542
Grinding mills classes, 108*t*
Gross domestic product (GDP), 559–560, 565
Guidewords and parameters of Node 1, 437*t*
Gymnosperms' lignin, 253

H

Hammer milling, 12, 13*f*
Harvesting, of algae, 164–167
Hazard and Operability Analysis (HAZOP), 429–430, 432–441, 434*t*, 438*t*, 441*f*
Hazard and operability analysis study procedure, 433*f*
Healthcare, lignin application in, 124
Hemicellulose, 72, 252–253, 398, 398*f*
Heterogeneous catalysts, 79–80, 171–173, 172*f*
Higher biodiesel blend exploration, 489–492
Horriba EXSA-1500, 359–360
Hot vapor filtration (HVF), 188*t*
House Bill (HB), 555–556
Human toxicity potential by either inhalation/dermal exposure (HTPE), 464
Human toxicity potential by ingestion (HTPI), 464
Hydraulic retention time (HRT), 322–323
Hydrocarbon (HC), 358, 371–375
Hydrochloric (HCl) acid, for substrate pretreatment, 210–211
Hydrodeoxygenation upgradation (HDO), 52
Hydrogen deoxygenation and hydro-sulfurization (HDS), 381–382
Hydrogen, 318, 335
Hydrolysis, 19, 403–404
  efficiency, 403–404
  enzymatic, 55–57
  lipid concentration effect on, 56–57, 57*t*
  particle size and concentration on, effect of, 55–56, 56*t*
  of renewable biomass, 212–216
Hydrothermal liquefaction (HTL), 53, 160, 167–174, 169*f*, 382–383, 387–389
  alkali salts, base, and acid catalysts, 170–171
  heterogeneous catalysts, 171–173, 172*f*
Hythane, 327

I

In situ transesterification (IST), 61–62, 81
Industrial Revolution, 159
Inhalable particulate matter (IPM), 379–380
Integrated anaerobic-aerobic bioreactor, 520–522
Integrated anaerobic-aerobic system, 522
Integrated gasification combined cycle (IGCC), 341
Intensification strategy, for biomass processing, 174
Inter- and intra-polymer hydrogen linkage, structure of cellulose with, 252*f*
International Energy Agency, 429

Investment priority projects (IPP), 564–565
Ionic liquids, 120
ISO 14040 standards, 499

J
Japanese Automobile Manufacturers Association (JAMA), 489–490
Jatropha curcas, 560
Jet milling, 12–14, 13*f*
Judgement/final comparison matrix, 467*f*

K
Kinetic
  analysis, 283–284, 289–298, 291*t*, 294*t*, 296*t*
  modeling, 94–95
  models, 281–284, 303–307, 305*t*
  theory, 280–281
Kissinger-Akahira-Sunose (KAS) integral method, 94, 100*f*
Klason method, 93–94
Kluyveromyces marxianus, 59

L
Lafarge Malaysia Bhd., 339
Large Scale Solar, 535–536
Levenspiel model, 304
Life cycle assessment (LCA), 404–406, 493–494, 498–499
  of microalgae conversion to biofuels, 148–152, 149*f*, 150*t*
    phases, 148–149
    system boundaries for, 148*t*
Life cycle impact analysis (LCIA), 148–149
Lignin, 72, 105–106, 253, 398
  application of, 123, 123*t*
    in Malaysia, 123–124
  content, 116–117, 117*t*
  extraction methods, 118–121, 118*f*
    acid hydrolysis, 119
    advantages and disadvantages of, 122*t*
    alkali hydrolysis, 119
    deep eutectic solvents, 120–121
    enzymatic hydrolysis, 120
    ionic liquids, 120
    organosolv, 120
    pyrolysis, 121
  monolignols/oligomer units, 254*f*
  properties, 114–116, 115*f*, 116*f*
  relocalization, 112
Lignocellulosic biomass (LCB), 89–90, 186, 250–251, 253–255, 256*t*, 259, 399–401
  agricultural biomass. *See* Agricultural biomass
  empty fruit bunches
    kinetic modeling, 94–95
    lignin content, determination of, 93–94
    pretreatment of, 93
    thermogravimetric analysis, of untreated and delignified, 94
  feedstock, 5–11
  major bonds exist in, 90
  pretreatment, 106–114
    methods, 90, 91*t*
    types of, 106–110
  recalcitrance nature of, 90
  results and discussion
    delignification process, pretreatment temperature on, 95–96, 95*t*
    pyrolysis kinetic, 99–100
    thermogravimetric analysis, 96–99, 97*f*
  sources of, 89–90
  types of, 199–200, 199*t*, 200*f*
Lignocellulosic wastes, 12–17
  chemical pretreatments, 14–16
  physical pretreatments, 12–14, 13*f*
  physicochemical pretreatments, 16–17
  technical problems, gasification of, 28–30
Limited government subsidy, 564–565
Lipid extraction microalga (LEA), 387–388
Lipid feedstocks, for food security, 75–76
  microalgae, 76
  nonedible oil crops, 75–76, 75*t*
Liquefaction, 53, 343–344
Liquid products, yield of, 343–344
Long-chain fatty acids (LCFA), 19
Low-transition-temperature mixtures (LTTMs), synthesis of, 93

M
Macroalgae, 162*t*
Malaysia
  available biomass-based products in, 125*t*
  BeWhere Malaysia, spatial representation of the bioenergy workflow in, 541*f*
  lignin application in
    agriculture, 123–124

fuel industries, 124
healthcare, 124
previous research on biomass/energy supply chain for, 538*t*
renewable electricity and biodiesel production in, 536*f*
Malaysia, biofuel development in
advanced biofuels, 494–497
biogas deployment, policies related to, 525–526
first-generation biofuels, 483–494
B5, B7
and B10 program, implementation of, 486–489
B20 and beyond, moving forward to, 489
higher biodiesel blend exploration, 489–492
issue and challenges, 492–494
national biodiesel program implementation, 485–492
petroleum depots, biodiesel blending facilities at, 485–486
standards, biofuel policy and development of, 485
technology development and commercialization, 484–485
issues and challenges, 526–528
biogas, 526–528
biomass, 528
second-generation biofuels, 507–525
bioethanol and biochemicals, 516–519
biogas utilization option, 524–525
biomass-to-gaseous fuel, 519–525
biomass-to-liquid fuel, 514–519
biomass-to-solid fuel, 510–514
briquettes, pellets, and torrefied solid biofuel, 510–513
integrated anaerobic-aerobic bioreactor, 520–522
MPOB-BEE biogas technology, 520
oil palm biomass cogeneration, 513–514
pyrolysis—bio-oil and biochar, 514–516
zero discharge palm oil mill effluent treatment, 522–524
supply chain optimization, 498–500
Malaysian oil palm industry, 505–506
Malaysian Palm Oil Board (MPOB), 484–485, 489–495, 511–512, 514–515, 520, 525–526
Material, emission of, 364–375
Mathematical model, 307–309
MATLAB software, 307
Max–min aggregation approach, 453
Mazda CX-5 laboratory engine test, 490, 491*f*
MCM-41
in catalytic pyrolysis, 26–27
Mechanical pretreatment method, of lignocellulose materials, 204–205, 206*t*
Mechanical pretreatment, 106–107
Mesocarp fiber (MF), 505–506, 513
Mesophilic operating temperatures, 19–20
Mesoporous aluminosilicates, 26–27
Methanogenesis, 19, 57–58
Metric tons (MT), 557–558
Michaelis–Menten model, 304
Microalgae, 62, 76, 162*f*, 162*t*, 202–203
applications, 152–154
CO_2 reduction, 152–153
pharmaceutical products, 153–154, 154*t*
wastewater treatment, 152
attached cultivation method, 142–148, 142*f*
biofilm development, 143–144, 143*f*
challenges of, 147–148
enclosure approach, 144–147, 144*f*
nonenclosure approach, 144–147, 144*f*, 145*t*
biomass, 201
advantage of, 202
bioethanol production from, 201, 202*f*, 203*t*
capillary-driven system, 144*f*, 145–147
conversion to biofuels, life cycle assessment of, 148–152, 148*t*
intermittent submerged system, 144*f*, 146–147, 146*f*
permeated system, 144*f*, 147
suspended cultivation method, 139–142
closed system (photobioreactors), 141–142
open systems (open ponds), 140–141, 140*f*
Microalgae-based biodiesels, 77*t*
Microporous zeolite catalysts, 26
Microwave irradiation pretreatment method, 205–206
Microwave-assisted transesterification (MAT), 80
Milled-wood lignin (MWL), 121
Milling equipment classification, 109*f*
Milling, 121
Million metric tons (MMT), 557–559
Minimum fuel selling price (MFSP), 383–388
Miura-Maki model, 283, 293

Mixed-integer linear programming (MILP), 540–541
Mixed-integer nonlinear programming (MINLP), 387
Mixing, 322
Molecular distillation (MD), 188*t*
Monod model, 304
Moringa oleifera, 520–522
MPOB-BEE high efficient biogas fermentation system, 520*f*
MPOB-BEE biogas technology, 520
MPOB-Tsinghua-Shandong University, 516
Myceliophthora thermophila, 408–409

N

National Biodiesel Program, 486–490
The National Biofuel Policy 2006, 485
National Biofuels Board (NBB), 556, 566
National Biomass Strategy 2020, 510
National Renewable Energy Laboratory (NREL), 253–255
  oil palm biomass compositions, 255*t*
The National Renewable Energy Policy and Action Plan, 498–499
Nationally Appropriate Mitigation Action, 429–430
Natural gas, 525*t*
Navier-Stokes equations principles, 309–310
Net Energy Metering, 535–536
Net energy ratio (NER), 148–149
Nickel-based catalysts, 30–31
Nitrous oxide (NO_x), 358–359, 369–371, 370*f*, 372*f*
Noncatalytic fast pyrolysis (NCFP), 381–382, 385
Noncatalytic transesterification, 60–62
Nonedible oil crops, 75–76
Nonisothermal method, 281

O

O_2, 369–371, 372*f*, 373*f*
Oil Deregulation Law, 561
Oil Industry Management Bureau (OIMB), 561
Oil palm biomass
  distribution of pyrolysis products from various types of, 514*t*
  and palm oil, energy potential from, 509*t*
  second-generation biofuels from, 511*f*
Oil palm biomass chemical potential, 251–255
Oil palm biomass cogeneration, 513–514
Oil palm biomass feedstock, 510
Oil palm biomass in 2019
  potential renewable energy from, 510*f*
Oil palm by-products, 318–320
Oil palm empty fruit bunches (OPEFB), 251, 260, 263
Oil palm frond (OPF), 124, 251, 261, 278–279, 284–298, 287*t*, 505–506, 512–515, 528
  kinetic plots of pyrolysis of, 290*f*
Oil palm mesocarp fibers (OPMF), 251, 263
Oil palm solid biomass (OPSB), 250–251, 255–258, 260–261, 268–270
Oil palm trunk (OPT), 251, 278–279, 284–298, 287*t*, 505–506, 510, 514–515, 517–518, 528
Oil palm-derived solid biomass, bio-succinic acid production from, 270–272, 270*f*
Oil reserves country, 182*t*
Omnibus Investments Code of 1987, 564–565
Operational expenditure (OPEX), 460
Optimal technology selection obtained via max–min-aggregation approach, 470*f*, 474*f*
Optimal technology selection obtained via weighted-sum approach, 470*f*
Optimal transportation design via weighted-sum approach, 474*f*
Optimum supply chain synthesis, parameters used for, 450*t*
Organosolv, 120
Ozonation-dispersed flotation, 166
Ozonolysis, 212

P

Palm biodiesel, 483–494
Palm empty fruit bunch (EFB), 446
Palm fatty acid distillate (PFAD), 484
Palm kernel shells (PKS), 251
Palm methyl ester (PME), 485, 487–489
Palm oil mill effluent (POME), 200, 319, 325–326, 329, 494–495, 496*t*, 505–506, 519–520, 522–528, 523*f*, 525*t*
  biogas potential from, 519*t*
  Performance of integrated anaerobic-aerobic bioreactor for codigestion of, 521*t*
  treatment stage of zero discharge pilot plant, 522*t*
Palm oil mills in 2019
  biomass types from, 506*t*

Palm oil mill, zero-emission from, 331*f*
Palm oil wastes
experiment materials and methods, 279–284
biomass preparation, 279
catalyst preparation, 279
Coats-Redfern, 281–282
kinetic analysis, 283–284
kinetic models, 281–284
kinetic theory, 280–281
Miura-Maki, 283
thermodynamic analysis, 284
thermogravimetric analysis, 279–280
Vyazovkin, 282–283
pyrolysis process, thermal degradation behavior of oil palm frond and oil palm
Palm shell (PS), 498–499, 505–506, 513–516
Paris Agreement, 535–536
Partial loads
CO_2 emission, 370*f*
NO_x emission, 370*f*
O_2 emission, 373*f*
THC emissions, 374*f*
Particulates, 32–33
Pedestrian fatality, risk of, 466*f*
Pelletization, 10–11
Petrochemical and bio-based succinic acid production processes, 265*f*
Petroleum depots, biodiesel blending facilities, 485–486, 486*f*
Petroleum fuel *vs*. biooil, 187*t*
pH, 321, 360–361
Pharmaceutical products, microalgae in, 153–154, 154*t*
Philippine Energy Plan, 558
Philippine National Standard (PNS), 560–561
Philippines
biodiesel (CME) refiners and producers in, 559*t*
bioethanol producers in, 557*t*
biofuels roadmap, 566*f*
coconut oil and sugar for the production of biofuels in, 555*f*
Ethanol Producers Association of, 558
gas pumps in, 556*f*
Philippine National Standard fuel quality standards, 561*t*
PNS/DOE QS 004:2017—Technical standard for B2 biodiesel blend in, 564*t*
PNS/DOE QS 008:2018—Technical standard for E10 bioethanol blend in, 562*t*
total energy requirement, 554
total power generation by fuel source o, 554*f*
Phillippines biofuel roadmap, 566, 566*f*
Photobioreactors, 141–142
Photofermentation, 327
Physical pretreatments, 12–14, 13*f*, 107
Physicochemical pretreatment, 16–17, 110, 111*t*
Plant cell wall, structure of, 71*f*
Plant oils, 11
biodiesel derived from, 74*t*
Plastic bag photobioreactor, 141
Policy and investment, 346–347
Potassium hydroxide (KOH), 406–408
Power and heat sectors, decarbonization in, 542–545
Power tariff subsidy (PTS), 542–547, 543*f*, 544*f*, 549
Power transmission requirement, 548*f*
Power, heat, and transport sectors, decarbonization in, 545–547, 546*f*, 547*f*
Presaccharification prior to simultaneous saccharification and fermentation (PSF), 404–406
Pressed mesocarp fiber (PMS), 498–499
Pressurized ammonium hydroxide (PAH), 260, 260*f*
Pretreatment methods, 106–114, 203–212, 204*f*, 514
advantages and disadvantages of, 213*t*
biological, 209
chemical, 209–212, 209*f*
acid, 210–211
alkaline, 211
ozonolysis, 212
coagulation/flocculation for, 166
effect of, 110–114
composition, 112–114
crystallinity, 110–112
lignin modification, 112, 113*f*, 114*f*
structure, 110–112
for empty fruit bunches, 93
physical, 204–208
mechanical, 204–205, 206*t*
microwave, 205–206
ultrasonication, 207–208, 207*f*, 208*t*
types of, 106–110

Pretreatment methods (*Continued*)
chemical, 110
mechanical, 106–107
physical, 107
physicochemical, 110, 111*t*
thermal, 107–110
Primary sources of energy, 159–160, 160*f*
Principal component analysis-aided optimization approach, 454–457, 456*t*, 468, 470*f*, 473, 474*f*
Principle component analysis (PCA), 454–455
Process and activity
emissions rate (g/kg biomass) for, 463*t*
energy and water consumptions for, 464*t*
safety index (ISI) score and job creation of, 465*t*
Propionic acid, 56–57
Proteins, 170
Pruning and replanting activities in 2019
biomass types from, 507*t*
Pyrolysis, 3–4, 51–53, 54*t*, 121, 184, 341–343, 380–386, 409–412
catalysis role in, 26–27
conditions and product yields, 24–25, 25*t*
vs. gasification, 33
heating rate of, 25
kinetic, 99–100
operating conditions of, 24, 24*f*
type of, 52*f*
Pyrolysis—bio-oil and biochar, 514–516
Pyrolyzed palm shell products and yields, 516*f*

R

Radial Diesel Combustion Engine, 357
Random index (RI) values, 453*t*
Rasamsonia emersonii, 408–409
Ratkowsky models, 306–307
Refined edible clean oil, 74–75
Renewable biomass, hydrolysis of, 212–216
Renewable energy, 138
conversion technologies of, 138*t*
Renewable Energy Act, 564–565
Renewable Energy Directives (RED and RED II), 9
Republic Act 9367, 555–557, 559–560
Rhodopseudomonas palustris, 327
Root mean square error (RMS), 307

S

Saccharification and fermentation, 404–406, 405*f*
Saccharomyces cerevisiae, 58, 516, 519
Scenario description, 542
Scheffersomyces stipitis, 404–406
Second-generation bioethanol, 199–201
Second-generation biofuels, 507–525
Second-generation biomass, 50
Separate hydrolysis and fermentation (SHF), 218–219, 243–244
Simultaneous saccharification and cofermentation (SScF), 404–406
Simultaneous saccharification and fermentation (SSF), 219–220, 243–244
Single-objective model, 447
Slow pyrolysis, 385–386
Sludge retention time (SRT), 321–323
Social awareness and marketing, 346
Social data, 464–466
Sodium carbonate (Na_2CO_3), 170
catalytic performance of, 170–171
Sodium hydroxide (NaOH), 257–258, 261–263, 359–362, 406–408
Sodium hydroxide pretreatment, 257–258, 258*t*
Solvent addition, 188*t*
Stakeholder relationship, 347
Standards, biofuel policy and development of, 485
Starch, 398–399, 399*f*, 400*f*
Starch-rich feedstocks, 197–198
State-of-technology (SOT), 388
Statistical Review of World Energy 2020, 159–160
Strain improvement, 221–224
Subcritical water (subH_2O), 174
Succinic acid (SA), 264–266
Succinic acid application/respective market share percentages, 267*f*
Sugar-rich feedstocks, 197
Sulfuric (H_2SO_4) acid, for substrate pretreatment, 210–211
Supercritical CO_2 (scCO_2), 174
Supercritical transesterification (SCT), 81–82
advantages of, 82
Supply chain, 346
optimization, 498–500
Suspended cultivation method, 139–142
closed system (photobioreactors), 141–142
open systems (open ponds), 140–141, 140*f*

Sustainability evaluation, dimensionality reduction in, 454*f*
Sustainable Development Goal 7—Affordable and Clean Energy, 471
Synthetic natural gas (SNG), 341

T

Tars, 31–33
Technical Association of the Pulp and Paper Industry (TAPPI), 253–255
  oil palm biomass compositions, 255*t*
Technical challenges, 345
  thermochemical conversion process, 345*t*
Technical Committee on Petroleum Products and Additives (TCPPA), 560–561
Technical maturity, 337
Technical readiness level (TRL), 337–339, 341–344, 344*t*, 347
Techno-economic analysis (TEA), 380, 383–385, 387–389, 388*t*, 404–406
Techno-economic analysis, 383–389
Technology, capital and operating expenditure of, 461*t*
Technology development and commercialization, 484–485
Technology readiness level assessment process flow, adaptation of, 337*t*
Technology selection, 467–471, 468*f*, 469*t*, 471*f*
Thermal pretreatment, 107–110
Thermochemical conversion pathways, 380–383, 381*f*
Thermochemical conversion technology, 51–54
  gasification, 53–54, 54*t*
  liquefaction, 53
  pyrolysis, 51–53
Thermodynamic analysis, 284, 291*t*, 294*t*, 296*t*
Thermodynamic study, 289–298
Thermogravimetric (TG), 284–288, 285*f*
Thermogravimetric analysis (TGA), 90–93, 96–99, 279–280
Thermogravimetric approach (TGA), 279
Thickening, 165–167
Third-generation bioethanol, 201–203
Third-generation biomass, 50
1000-h endurance test, test vehicle under evaluation for, 490*f*
Three different models, linear expression of, 284*f*
Torrefaction, 22–23, 52–53
Total HCs (THC), 358–359, 371–374, 373*f*, 374*f*
Total suspended solids (TSS), 165
Transesterification, 59–62, 406–408, 407*f*, 408*f*
  biocatalyst, 82–83
  catalytic, 59–60
  in situ, 81
  for lipid conversion, 73–74, 73*f*
  microwave-assisted, 80
  noncatalytic, 60–62
    in situ, 61–62
  supercritical, 81–82
  two-step acid base, 80
Transportation design, 471–475, 472*t*, 473*t*
Transportation sector, B10 implementation in, 488*t*
Transportation-related expenses, 462*t*
Trichoderma reesei, 408–409
Triglycerides, 73–74
Trunk in, 284–288
  oil palm frond and oil palm trunk thermal decomposition, effect of heating rates on, 288
  catalyst on oil palm frond and oil palm trunk thermal decomposition, effect of, 288–289
  kinetic analysis and thermodynamic study, 289–298
Tsinghua University and TUS Deqing Bioenergy Co., Ltd., 492
Two-stage reactors, biohythane production with, 328*t*
Two-step acid base transesterification, 80

U

Ultrasonication pretreatment method, 207–208, 207*f*, 208*t*
Ultrasound, 17
Unit material cost, 461*t*
United Nations Development Programme, 341
United Nations Framework Convention on Climate Change, 265
United States Department of Energy, 265
United States Energy Information Administration (EIA), 69–70, 277–278
Upward anaerobic sludge blanket (UASB) reactor, 323
Used cooking oil (UCO), 358–362

V

Various biofuel production technologies, economic feasibility analysis of, 415*f*
Volatile fatty acids (VFAs), 55–56, 320–321, 323–324, 326
Volatile matter (VM), 72
Vyazovkin (V) method, 282–283, 293

W

Waste cooking oil biodiesel
procedure, 359
materials and equipment, 359–362
results and discussion, 362–375
combustion and torque, heat of, 362–364
material, emission of, 364–375
Waste cooking oil, biodiesel production from, 365*t*
Waste Cooking Oil Methyl Ester, 358
Waste Reduction (WAR) Algorithm, 460–462, 464
Wastewater treatment, microalgae in, 152
Water extraction, 188*t*
Weighted-sum approach, 451–453
Wheel to bioenergy (WTB), 148

X

Xylose-rich/pentose sugar, fermentation of, 224

Z

Zeolites, 26, 173
Zero discharge palm oil mill effluent treatment, 522–524

VALUE-CHAIN OF BIOFUELS

Fundamentals, Technology, and Standardization

Value-Chain of Biofuels presents the fundamental aspects of biofuel productions that encompass conversion technologies of biomass to biofuels, feedstock pre-treatment and associated policies, regulations, and standardizations. The chapters are divided into three parts where Part 1 explores current progress of biofuels' industries, pre-treatment technologies of biomass feedstocks, and conversion processes of biomass to biofuel. Part 2 reviews the different pathways to produce biofuels and biochemicals, including bio-oil, bioethanol, biogas, bio-hydrogen, and bio-succinic acid. Part 3 presents the policies, regulations, and standardizations associated with biofuel productions and applications. Case studies are included based on reviews from both academics and industries, discussing on the economics of biofuel production, in addition to the analysis of biomass and biofuel supply chains. Through these overviews the book provides a reference for the academics, students, researchers, and practitioners working in the fields of bioenergy and renewable energy, and of interest to chemists, bioprocess engineers, chemical engineers, and industrial practitioners in agriculture and petrochemical sectors.

KEY FEATURES

- Gain academic and industry perspectives on biofuel production from lab-based experimentation to pilot and industry scale production, through case studies
- Contain analyses of biomass conversion technologies to biofuels and biochemicals
- Provide clear and concise text

ABOUT THE EDITORS

Suzana Yusup is the Director of Higher Institution Center of Excellence, Center for Biofuel & Biochemical Research (CBBR) Program @ Head of Universiti Teknologi PETRONAS (UTP) CBBR and is a full Professor at Chemical Engineering Department (UTP), Malaysia. Her research interests are related to biomass conversion to biofuels and biochemicals, material development, and greener processes. Graduated in Chemical Engineering from University of Leeds (United Kingdom) in 1992, Master of Science (Chemical Engineering) from the University of Wales Swansea, UK, and Philosophy Doctorate in Chemical Engineering from University of Bradford, UK. To date, Professor Dr Suzana Yusup has authored one book, 26 book chapters, more than 300 scientific articles in high-impact journals and as conference papers, and 21 patents (including 10 granted patents). She has more than 20 years of experience in teaching and is active in research related to thermochemical conversion of biomass to biofuels and value-added products. She is a Charted Engineer, Charted Scientist under the Institute of Chemical Engineer UK, , Member of Energy Institute UK, a registered professional engineer (Chemical) with Board of Engineers Malaysia, Fellow of Academy of Sciences Malaysia, Leaders in Innovation Fellowship under Malaysia Industry-Government Group for High Technology and the Royal Academy of Engineering UK, Senior Research Fellow of Resilience Development Initiative, Indonesia, and Fellow of International Bioprocessing Association.

Nor Adilla Rashidi holds a bachelor's degree in chemical engineering (Hons.) (2010), Master of Science degree (MSc) in Chemical Engineering (2014), and a Doctorate degree (PhD) in Chemical Engineering (2019) from Universiti Teknologi PETRONAS, Malaysia. Her main research interests include biomaterial development, wastewater treatment, and carbon capture and storage. To date, she has published over 20 peer-reviewed articles in numerous high-impact journals including *Energy, Chemical Engineering Journal*, and *Journal of CO2 Utilization*. She is currently affiliated with several professional associations, including Malaysia Board of Technologist (Graduate Technologist), Board of Engineers Malaysia (Graduate Engineer), and Institution of Chemical Engineers (Associate Member).

ISBN 978-0-12-824388-6

9 780128 243886

ELSEVIER

elsevier.com/books-and-journals